EFFECT OF PIPE ROOF SUPPORT ON THE GROUND SETTLEMENT INDUCED BY SHALLOW TUNNEL EXCAVATION

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2016

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by

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Thesis submitted in fulfilment of the requirements for the degree of Master of Science

December 2016

ACKNOWLEDGEMENT

In the name of Allah, the Entirely Merciful and the Especially Merciful.

Alhamdulillah, all praises to Allah and salawat to Nabi Muhammad S.A.W. I am so grateful to Allah for all the time, the strength, the health and the convenience that had been given to me to in completing this thesis. First, I would like say my deepest love and gratitude to my parents for their unconditional prayers for my grateful achievement and successfulness. I would like to express my highest gratitude to my supervisor, Professor Ir. Dr. Mohammad Razip Selamat for all his sharing of knowledge, motivation, sincere comments and suggestions throughout the past years until the completion of this thesis. A great appreciation also goes to my co-supervisors, Dr. Mohd Ashraf Mohd Ismail and Dr. Muhd Harris Ramli for their dedication, active co-operation and passion in providing useful information and tools regarding the research. I also would like to express my gratitude Encik Bani Faidzzainami Baniyamin, Assistant Engineer of computer laboratory for his assistance during my presence at the lab. Last but not least, my beloved wife, Siti Asma Abd Latif for her support, love and patient.

-*Mohd Fandey Abdul Latif, May 2014*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two-dimensional
CCTV	Close-circuit television
ELS	Electronic laser system
EPB	Earth pressure balance
FE	Finite element
FEM	Finite element model
HDD	Horizontal Directional Drilling
MT	Microtunnelling
MTBM	Microtunnelling boring machine
NATM	New Australian Tunnelling Method
PLUS	Projek Lebuhraya Utara-Selatan
PTMT	Pilot tube microtunnelling
RCP	Reinforcement concrete pipe
TBM	Tunnel boring machine

LIST OF SYMBOLS

a	Tunnel radius
c	Cohesion
c_u	Undrained shear strength
d	Tunnel diameter
E	Young's modulus
g	Gap parameter
G_P	Spacing between tunnel crown and lining
h	Vertical distance from the ground surface to the center of tunnel
i	Inflection point
i	Value of y-axis corresponding to point of inflection of Gaussian trough
n	Number of dimension
$Ø$	Angle of friction
p_0	Initial total vertical stress
p_i	Uniform tunnel pressure
R	Radius of volume loss
r	Distance from center of tunnel
S_{max}	Maximum settlement
S_p	Spacing between two identical tunnels
S_z	Vertical displacement
U_{3D}	A spatial elastic-plastic deformation which contribute to the three dimensional displacement in front of the tunnel path

V_{exc}	Volume of excavated soil
V_s	Volume of Gaussian settlement trough per meter length
w	Vertical deflection
w_{max}	Maximum settlement
x	Horizontal distance
Z	Vertical distance
Z_0	Vertical distance from the undeformed surface to tunnel axis
Z_0	Ground level
α	Exponent for volumetric compressibility
γ	Unit weight of soil
δ	Ovalization effect
ε	Uniform radial displacement
σ	Normal stress
σ_0	Effective overburden stress
τ	Shear stress
ω	workmanship parameter

KESAN PENGGUNAAN PENYOKONG ATAP PAIP TERHADAP MENDAPAN PERMUKAAN TANAH OLEH PENGGALIAN TEROWONG CETEK

ABSTRAK

Masa kini, ruang bawah tanah telah menjadi bahagain penting di dalam kemajuan manusia yang melibatkan ekonomi, sosial dan keperluan. Sesetengah kawasan yang membangun amat memerlukan penyelesaian yang lebih baik untuk sistem pengangkutan yang effisien. Terowong cetek biasanya dibina di bawah jalanraya yang sedia ada dan di bawah kawasan yang mempunyai ruang yang terhad. Dalam kajian ini, penyokong atap paip telah dikaji untuk mendapatkan fungsi optimum sistem tersebut yang bertindak sebagai penyokong sementara bagi membolehkan kerja penggalian terowong dijalankan dengan selamat. Atap paip penyokong tersebut dibina dengan memasang serta menyusun beberapa cerucuk konkrit di bahagian atas terowong dengan menggunakan mesin penggali terowong mikro (MTBM). Analisis tersebut telah dijalankan dalam beberapa kes yang berasingan dengna menggunakan model 2D-Finite Element. Model-model tersebut telah dibandingkan berdasarkan tiga bentuk terowong iaitu bulat, ladam kuda, dan empat segi sama. Setiap bentuk terowong telah menjalani beberapa analisa seperti kesan penggunaan penyokong atap pain terhadap kedalaman (0.0*d*, 0.5*d*, 1.0*d* and 2.0*d*) dan jarak di antara dua terowong berkembar (0.0*d*, 0.5*d*, 1.0*d* and 2.0*d*). Bahagian terakhir analisa adalah mengenai pembuktian magnitud mendapan hasil ke atas projek yang menggunakan system penyokong atap paip di Padang Rengas, Perak. Berdasarkan analisis yang telah dijalankan, keputusan menunjukkan bahawa mendapan telah berkurang sehingga 90% dengan pemasangan atap paip penyokong tersebut. Magnitud mendapan telah berkurang sehingga 60% apabila kedalaman

terowong ditingkatkan. Bagi terowong berkembar, mendapan telah bertambah daripada sehingga 70% di terowong kedua kesan daripada penggalian yang dilakukan di terowong yang pertama yang menyebabkan gangguan terhadap kekuatan tanah.

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ABSTRACT

Nowadays, underground space has become an important part of human development involving economics, social and needs. Some areas especially in the urbanized surroundings are in need of a better solution for an efficient transportation system. Shallow tunnel usually constructed beneath an existing highway or an area with limited spaces to improve transportation network. In the present study, pipe roof support was analyzed to determine the optimum function of its system that acts as a temporary support. The pipe roof is formed by installing a number of horizontal concrete piles at the crown of the tunnel by using microtunnelling boring machine (MTBM). The analyses were done in a few separate cases by using 2D-Finite Element modeling. The models were differentiated according to three tunnel shapes which are circular, horseshoe and square. Each tunnel had been analyzed according to the effect of the pipe roof tunnel to depth (0.0*d*, 0.5*d*, 1.0*d* and 2.0*d*) and spacing between twin tunnels (0.0*d*, 0.5*d*, 1.0*d* and 2.0*d*). The last part of the analyses is the verification study on a pipe roof tunnel project at Padang Rengas, Perak. A simple ground profile of the tunnel project had been created by using the information gathered from the bore log of the in-situ. Based on the analyses, the results had shown that the settlement has been reduced up to 90% with the installation of pipe roof system. As the tunnel depth increase, the magnitude of settlement above the tunnel has reduced up to 60%. Meanwhile, for the twin tunnels, the magnitude of settlement has increased up to 70% at the second tunnel due to the excavation of the first tunnel that cause disturbance to the soil strength. The magnitude of settlement

of a twin tunnels also reduced from up to 58% when the spacing between the tunnels increase.

CHAPTER ONE

INTRODUCTION

1.1 Introduction to Shallow Tunnelling

The underground engineering nowadays is very crucial especially when dealing with a limited space. It is part of the infrastructure that influences the lifestyle of the modern society and had been applied for a wide range of services such as highways, railways, subways, material storage, sewage and water transport (Hashash et al., 2001). For the last century, the worldwide development has shown the conflict between the demand and supply. The increasing in demand will simultaneously increase in supply. In urban areas, the acquired consciousness of preservation of building and environment together with the requirement of life improvement has raised many issues and difficulty in executing a tunnelling project.

This recent, many issues regarding settlement of building and highways have gained the attention of the engineering world. The settlement does not only produce hazard to the structure around the vicinity, but it also will increase the risk of accident in the tunnel. There are few reasons that contribute to this problem such as poor geotechnical condition of the ground, the presence of water table or aquifer, and the shallow depth of tunnel excavation. Shallow tunnel are usually excavated by using delicate method to avoid excessive vibration such as hydraulic rock splitter where a number of holes will be drilled before the hydraulic splitter takes place inside the drilled holes to create fracture in the rock mass. This method is able to replace the drill and blast method that normally produce a high impact of vibration. However, by performing such a method will not guarantee that settlement will not occur. There are methods that can be incorporated in order to minimize the effect of settlement during the tunnel construction. In this thesis, the author will focus on the effect of pipe roof application system to the ground surface settlement. Pipe roof system is a temporary support that helps contractor to hold the overburden while performing the tunnel excavation work.

Shallow tunnelling is not the first priority when dealing with underground subway. But sometimes it can be the option to solve many problems that might be the getaway to bigger improvements that influence the human lifestyle and economy. One of the closest examples of today shallow tunnelling advantage is the construction of SMART system in Kuala Lumpur. The 13 km long tunnel was built for a multiple functions both as an underground road for traffic deviation to reduce traffic congestion and storm-water diversion duct to mitigate the high risk to flooding in the center of the city. Thanks to the underground technology that we have today, we are able to excavate tunnels under small overburden to solve this kind of problem that usually bring deteriorate effect to the local economy and properties.

1.2 Challenges in Shallow Tunnelling

The challenge in shallow tunnelling is not only related to the technique of construction, but also the level of sustainability that need to be achieved. The construction of shallow tunnel either in urban and rural area must abide the law and regulation of construction and environment. The disturbance created during the tunnel construction will cause discomfort to the local community as well as interruption to the integrity of building structure. The interruption that occurs above the surface has to be handled and analyzed wisely. This includes the appropriate traffic management on the involved area, well site arrangement, an efficient noise and dust control, and high safety alert. As an engineer, this is a challenge that needs to be considered so that the disturbance can be reduced to lowest level as possible and at the same time providing a quality work within the cost and time.

The poor quality of the ground condition is one of the important elements that need to be considered in the design and construction method of shallow tunnel. Shallow depth usually consists of loose material of soils such as pit soil that contains high organic concentration with a very low bearing capacity. The depth of topsoil can extend until a few millimeters into the ground until the subsoil layer. Without an appropriate surface treatment, it can be easily washed away by rain and prone to erosion. An area consists of a man made fill usually brings other kind of difficulty such as the unwanted of an unknown material that buried under the filled area that somehow need to be cleared up. This will indirectly increase the amount of cost and time of the project. On top of that, the remaining of historical relic that exists in the ground must be handled by the right authorities before the project can begin. The existing underground cables and services at urban area must be assessed and identified. Perhaps the risk and possibility of damage caused by the settlement that induced during the tunnelling process will allows the engineer to think again for rerouting the tunnel advancement.

Surface settlement due to shallow tunnel excavation is inevitable. Even under a strict monitoring and control, settlement will always occur due to many factors. The factors usually related to the quality of ground condition, workmanship, the application of support pressure during tunnelling, the level of ground water table and the water flow in aquifer. The stratification of soil due to the process of transportation and deposition has created a multiple layers of soil that has low residual strength. The lack of experience and the incapability to propose a technical solution for the settlement issue which consistent to the risk reduction slowly will put the project into jeopardize. This involves the selection of tunnelling method and the monitoring system that had been imposed to observe the level of settlement.

Besides the tunnelling method, the other factor that must be given attention is the internal support pressure that must be greater than the critical support pressure. This depends on the type of ground that will influence the principal and operational criteria of the temporary support during the tunnelling such as pipe roof system, lining system, shotcrete, rock bolts and steel girder. Pipe roof system is currently a system that utilized steel pipe which contains grout to reinforce the crown of the tunnel before excavation can be preceded. This system will be thoroughly highlighted later throughout this thesis as the main focus. Therefore, the effort to reduce the settlement to the minimum level as possible must be conducted conscientiously as one the important elements in reducing further problem that supposedly can be well predicted.

1.3 Application of Pipe Roof System in Shallow Tunnelling

Pipe roof system generally divided into two which are forepolling method and pipe arch method. Both methods provide the function as a temporary support for tunnelling. These methods use the same idea of reducing settlement during the tunnelling process. Nowadays pipe roof is widely used for tunnel construction especially in urban area to reduce the settlement that affecting the adjacent structure. Pipe roof method serves by using trenchless technique which used to build the underground passage to cross highways, railways and airport runaway. It has been proven to have a good effects in underground construction engineering such as in Asia as well as Europe (Ge, 2005).

Forepolling method or also known as umbrella arch method (Ocak, 2008) consists of series of steel or fiber glass pipe that had been arranged parallel to the tunnel axis or at a certain angle. The inserted pipe will be injected with grout to create a stiffer reinforcement to allow safe excavation to be conducted in the tunnel. The function is to maintain the exact ground profile and stabilize the rockmass. It is functioned as a temporary support and will be added with permanent support such as bolts and shotcrete (Kontothanassis *et al*., 2005). It is typically in areas with sandy or silty soil, squeezing and fragmented rock. Forepolling is also frequently used in sections of insufficient rock cover for example at the tunnel entrance area where the jointed roc mass may lack of the horizontal stresses required to keep the rock block intact (Osgoui *et al*., 2011). **Figure 1.1** shows the cross and longitudinal section of the forepolling method.

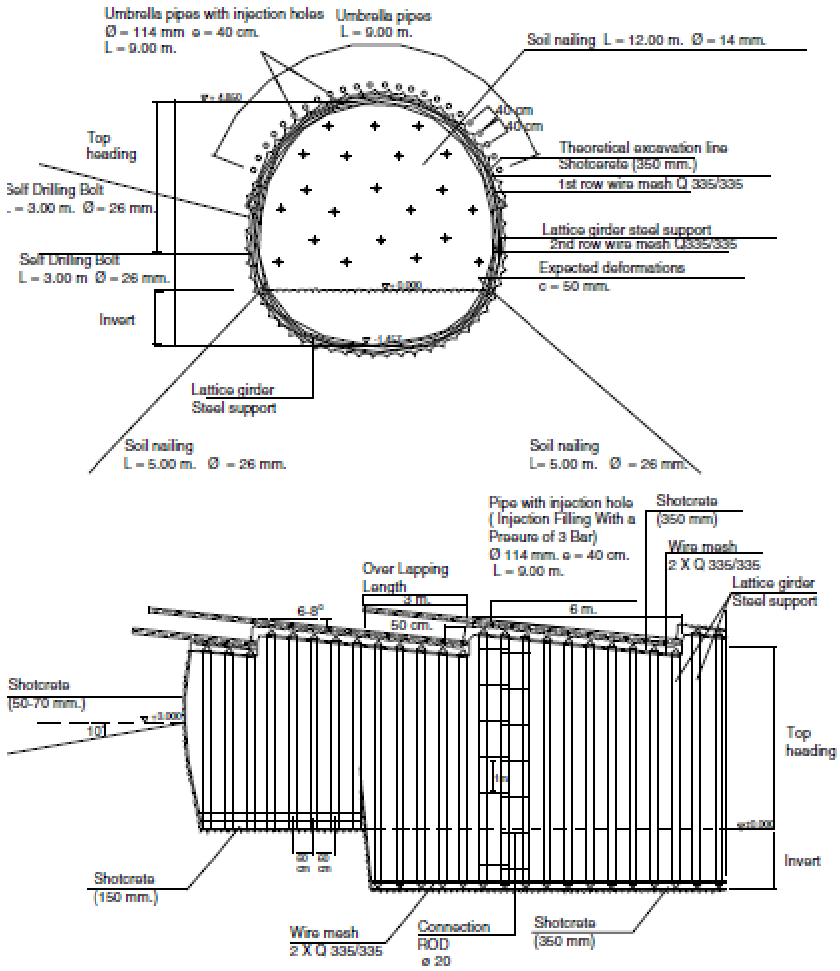

Figure 1.1: The cross and longitudinal section of forepolling method (Ocak, 2008)

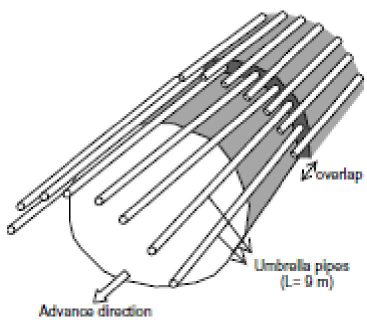

Figure 1.2: Overview of forepolling method (Ocak, 2008)

The pipes were normally installed at the crown of the tunnel. The diameter of the pipe usually ranged between 60mm to 200mm with a wall thickness of 4mm to

8mm. The length of the pipe are generally depends on the inclination of its angle where it must consider the depth of the tunnel. The depth of the tunnel usually ranges between 6m to 12m. The overlapping length usually exists between previous installed pipe and the next installed pipe as shown in **Figure 1.1** and **Figure 1.2**.

In the other hand, pipe arch method is utilized by installing a series of pipe which parallel to the tunnels axis. It consists of series of steel pipes that installed horizontally according to the tunnel axis. Steel pipe are used in this method by drilling them around the tunnel periphery towards the tunnel axis before excavation and later supplemented with grouting which inserted through the pipes to form pipe roof structure to strengthen the surrounding ground (Yang *et al.*, 2008). Sometimes interlocking steel pipes are being used to strengthen the link between the steel pipes. The diameter usually ranged between 0.5m to 1.0m. The application of pipe roof system is normally suitable for a large diameter of shallow tunnel on short distance. This system is an alternative to cut and cover method where sometimes a certain infrastructure such as highway needs to be maintained on the location of the shallow tunnel construction. Further information and details will be given on this system in the next chapters as the main focus of this thesis. **Figure 1.3** shows the schematic view of the pipe roof system.

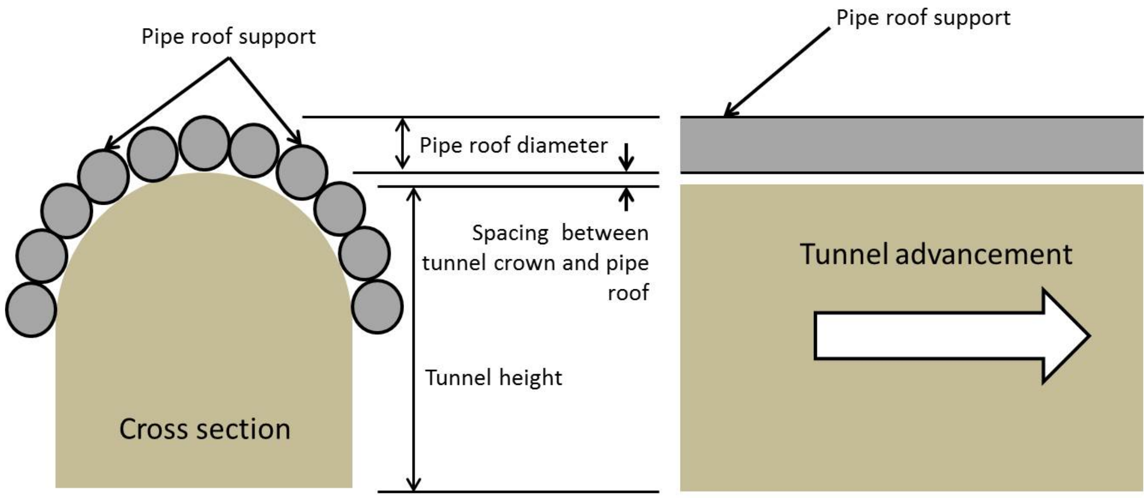

Figure 1.3: Schematic view of pipe roof system

1.4 Problem Statement

The usage of land has been intensified since many centuries ago for the purpose of living such as providing human residence and agricultural medium. These elements are important to provide a better life environment condition. The equal attention must be given in this respect to the increasing demand by the local communities to have more areas free of road traffic (Leca *et al*., 2007). Based on this matter, the requirement of undertaking the underground construction is almost inevitable to merge the demand for services and facilities. In order to realize the demand, the possible effects to the adjacent structures and underground services must be considered.

Currently, the tunneling induced ground settlement has become one of the major issues especially in urban tunnel construction. Urban tunneling usually involves an underground construction with low overburden and shallow depths up to less than 4m (Osgoui *et al.*, 2011). Pipe roof system has been used in many projects